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EXECUTIVE SUMMARY

SEISMIC TESTING OF NATURALLY AGED EXIDE FHC-19 STATION BATTERY CELLS

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A sample of ten year old lead acid storage batteries from the Calvert Cliffs Nuclear Power Station (Baltimore Gas and Electric Company) were tested on a shaker table. Although the intensity of the shaker tests reached the full capacity of the table, none of the six cells tested showed a significant loss of voltage during the simulated earthquakes. However, only two cells could deliver 80% of their rated capacity following the seismic tests. Four cells were disassembled and examined after the shaker tests. Bus bar material from the positive side of the cells was corroded and brittle (although not cracked) and active material on the positive plates was hard and cracked. Loss of active material from the positive plates is suspected as the main causes of the reduced capacity of the cells.

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To Mr. B.A. Oliver
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SEISMIC TESTING OF NATURALLY AGED EXIDE FHC-19 STATION BATTERY CELLS

1.0 INTRODUCTION

The large lead acid storage battery cells that are the subject of this report are used to provide dc power for nuclear power stations during and after an earthquake. It is well known that these cells deteriorate with age and it is normal practice to test them at regular intervals to ensure that they are capable of meeting a specified level of performance. What is not so well understood however, is the effect of age on the mechanical fragility of the cells and whether the cells would be capable of surviving seismic events at the operating basis earthquake (OBE) or safe shutdown earthquake (SSE) levels and to continue to meet the load profile required by the Class 1E system. Because of the importance of storage batteries to the Class 1E system, the US Nuclear Regulatory Commission has requested Sandia National Laboratories (SNL) to evaluate the impact of aging and seismic exposure on battery capacity. Ontario Hydro has been subcontracted to carry out capacity and seismic shaker tests on naturally aged cells supplied by SNL from several US nuclear power stations (SNL contract 47-4077). The program addresses possible variations between designs produced by different manufacturers.

This report describes the results of a series of experiments carried out at the Ontario Hydro Research Laboratories on a set of ten year old Exide FHC-19 cells from the Calvert Cliffs Nuclear Power Station (Baltimore Gas and Electric Company). During the shaker tests, the cells delivered uninterrupted power. However, during the discharge tests that followed the shaker tests, only two of the six cells could deliver more than 80% of their rated power. To determine the nature of the deterioration of the internal components of the cells, several cells were disassembled for inspection and metallurgical examination. It was found that the active material on the positive plates was hardened and, in many instances, cracked, and that

a significant volume of this material had fallen out of the plate grid. Corrosion and brittleness was also noted in the positive bus material.

This report summarizes the tests and results for this batch of cells. A more detailed discussion of the tests and results is contained in reports C84-120-P (battery condition and performance)/1/ and 84-418-P (seismic test results)/2/.

The tests described here were part of a larger program of testing of aged cells. Other cell types tested to date have included Gould FKR (Pickering NGS)/3,4,5/. Gould NCX2250 (J.A. Fitzpatrick NPS)/6/, Exide EMP-13 (Shippingport NPS)/7/ and C&D LCU-13 (North Anna NPS)/8/.

2.0 TEST METHODS AND RESULTS

2.1 Initial Inspection and Conditioning

Ten Exide FHC-19 cells were received from the Calvert Cliffs plant. Except for a small crack on the top plate of one cell, no external damage was found. On the negative plates, regular horizontal and vertical cracks were observed in the sponge lead active material. Small hollow blisters were found near the tops of these plates. The positive plates were bowed (severely in two cells). There was 3 to 5 mm of sediment in the bottoms of the cells, principally lead oxide, but with pockets of lead sulphate. The cells were conditioned (charged and discharged several times to stabilize their condition) and tested for capacity. The electrical state of the cells prior to the seismic tests is summarized in Table 1.

2.2 Seismic Testing - Single Cells

The shaker table and instrumentation used in these experiments is described in Reference /2/. The table provides independent motion in three directions. The motion is based on a quasi-random signal, filtered to match the frequency content of a typical earthquake. The duration of each test was 30 s. The seismic test method conformed to the recommendations of IEEE Std 344-1975 and IEEE Std 501-1978/9/.

For the first phase of the seismic testing, the cells were mounted individually on the shaker table in a stiff frame, designed to minimize relative motion between the cell jar and

the table (see Figure 1). This series was intended to investigate possible failure modes of internal components. The rig was designed to minimize the danger of jar failure and acid spill. Accelerometers were mounted on the base of the frame and on the top of one of the posts of the cell.

Each cell was subjected to a series of tests at successively higher acceleration levels. The test sequence for each cell is shown in the test log given in Table 2. In this record, the acceleration level for each test is quoted in terms of the span setting of the amplifier in the shaker control system. Because the input motion is random, it is impossible to define the relationship between span setting and acceleration exactly. The table below is approximate.

Span Setting	ZPA of Fitted IEEE 501 Spectrum (g)	Maximum Acceleration (g)
3	0.6	1.5
4	0.8	2.0
5	1.0	2.5
6	1.3	3.2
7 (machine limit)	1.5	3.8

During the seismic tests, the cells were discharged against a resistive load at a 1 h discharge rate. They were considered to have passed a seismic test if they remained above 1.75 V during and immediately after the test. The cells were shaken at progressively higher levels up to the machine limit. Each of the four cells that were tested in the single cell frame passed all of the tests. Table 2 provides a log of the test sequence, while Table 3 summarizes the results. Figures 3-14 show response spectra for the final test with each cell. There were no sudden drops in cell voltage during any of the shaker tests.

The seismic test results are presented in this report and in Reference /2/ in terms of acceleration response spectra of the table motion. To provide a convenient means of comparing the acceleration levels encountered during various tests, each test spectrum is compared to a normalized spectrum defined in IEEE Std 501-1978. The shape of this spectrum is intended to reflect the frequency content of the "typical" seismic environment for electrical equipment. The intensity of the simulated seismic motion is expressed in terms of the ZPA (zero period acceleration) which closely corresponds to the peak acceleration of the base.

2.3 Jar Fragility Test

Earlier testing (Gould NCX2250 cells from J.A. Fitzpatrick NPP/6/) has shown that cracks in the jars would propagate more readily if the cell was mounted loosely in the test frame. A single test was carried out with an FHC-19 cell loosely mounted in the frame. In this case, the cell jar had no sign of prior cracking and no damage occurred as a result of the test.

2.4 Multi Cell Rack Test

The single cell tests were designed to focus on failure modes of internal components. To examine the possible failure modes that would be encountered with normal in-plant mounting arrangements, a shaker test was carried out on a set of three cells mounted on a rack that resembled typical seismically qualified battery racks (see Figure 2). The test log and results are shown on Tables 2 and 3. Figures 15 and 16 show response spectra for the final test on the rack mounted cells. Again, no failures occurred.

For practical reasons, the rack that was used for these tests held only three cells. Full scale racks in generating stations are typically much longer. The present tests could be non-conservative since long strings of cells could, under violent shaking, impose large impact loads on cells at the end of the string. These tests provide no positive indication that this is a potential source of trouble. Nevertheless, we suggest that in severe seismic environments, it would be beneficial to separate cells into groups of three or so, with rigid partitions on the rack and flexible electrical connections between groups.

2.5 Post Seismic Capacity Tests and Inspection

Following the shaker table tests the cells were re-tested for electrical capacity. The results of these tests are shown on Table 1. There was a significant loss of discharge capacity for all cells. Only two of the cells had post-test capacities, (as measured from the start of the seismic test series) that met the acceptance criterion of more than 80% rated capacity.

Following these tests, four of the cells were disassembled and inspected. Internal components showed various types of age-related damage, including corrosion (bus bars and plates), cracking (positive and negative plates), hardening and loss of

active material (positive plates) and gas blistering (negative plates). The degree of damage noted during the post-test inspection correlated with the drop in capacity that occurred because of the simulated seismic shaking.

3.0 CONCLUSIONS

1. The ten year old Exide FHC-19 cells that were the subject of this study showed signs of age related degradation. Some of these signs (plate warping and sedimentation) could be observed from the outside of the cells, while other indications (corrosion damage and brittleness) were discovered when the cells were dissected after the shaker tests.

2. All of the cells that were tested on the shaker table delivered uninterrupted power during repeated strong shaking. There was however, significant loss of electrical capacity, to the extent that four of the six cells were not capable of delivering 80% of their rated capacity (the normal acceptance level for emergency power supply batteries).

3. Internal components of all of the cells that were disassembled had various types of age related damage, including corrosion, plate swelling, cracking and blistering. The amount of sediment present was uncharacteristically large for lead-calcium alloy cells.

4. There were no signs of damage to the jars during any of the tests. This includes tests where a cell was free to move in the test frame (and hence would be subject to impact loads) and tests with multi-cell racks.

4.0 ACKNOWLEDGEMENTS

Test cells and funding for this project were provided by Sandia National Laboratories. This support is gratefully acknowledged. Lloyd Bonzon and Don Hente of SNL are thanked for their large contribution to the project. Within Ontario Hydro, contract coordination was handled by the Electrical Design Department. We are grateful to Colin Royce and Jerry Schendel for their efforts. Much of the testing and analysis was carried out by Brian Aucoin of the Chemical Research Department and

Gordon Paulson of the Mechanical Research Department. Their able work was essential to the successful outcome of the project.

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8. J.D. Tulk, D.A. Black, W.J. Janis and B.M. Kukreti, "Seismic Testing of Naturally Aged Exide LCU-13 Station Battery Cells". Ontario Hydro Research Division Report B84-425-K.

9. IEEE Std 501-1978, "IEEE Standard, Seismic Testing of Relays". The Institute of Electrical and Electronics Engineers Inc., 1978.

TABLE 1

CELL CAPACITIES BEFORE AND AFTER SEISMIC TESTING

Cell	Time to 1.75 VPC at 3 h Rate Rate (min)			Percent of Rated Capacity at 3 h Rate		
	Pre-Seismic	Post-Seismic*	Post-Seismic Plus Seismic	Pre-Seismic	Post Seismic*	Post-Seismic Plus Seismic**
10	180	104	118	100	58	66
15	155	104	131	86	58	73
23	155	121	135	86	67	75
35	155	121	132	86	67	73
51	170	162	177	94	90	98
57	180	149	164	100	83	91

* Cells not recharged following seismic testing.
** Capacity during seismic test at 1.0 h rate converted to 3 h capacity and added to post-seismic capacity, as discussed in Report C84-120-P.

TABLE 2

TEST HISTORY - CALVERT CLIFFS NPP - EXIDE - MODEL FHC-19

CELL	DATE	TIME	RUN	SPAN	COMMENTS
57	July 23/84	2:00	1	3	No load applied
57	July 23/84	2:02	2	3	Load on
57	July 23/84	2:03	3	4	
57	July 23/84	2:05	4	5	
57	July 23/84	2:07	5	6	
57	July 23/84	2:10	6	7	Plotted
15	July 23/84	3:10	1	4	
15	July 23/84	3:11	2	5	
15	July 23/84	3:12	3	6	
15	July 23/84	3:13	4	7	Plotted
15	July 23/84	3:22	5	7	Clamps Loose
51	July 24/84	10:08	1	4	
51	July 24/84	10:09	2	5	
51	July 24/84	10:10	3	6	
51	July 24/84	10:11	4	7	Plotted
51	July 24/84	10:12	5	7	Clamps Loose
35	July 24/84	11:11	1	4	
35	July 24/84	11:12	2	5	
35	July 24/84	11:13	3	6	
35	July 24/84	11:14	4	7	Plotted
		Rack Test			
23,10,5	July 25/84	2:45	1	4	
23,10,5	July 25/84	2:46	2	5	
23,10,5	July 25/84	2:47	3	6	
23,10,5	July 25/84	2:49	4	7	Plotted

TABLE 3

TEST RESULTS

CELL NUMBER	DIRECTION	ZPA (9)	SPAN
57	X-BASE	1.31	7
57	Y-BASE	0.98	7
57	Z-BASE	1.59	7
57	X-TOP	1.31	7
57	Y-TOP	0.83	7
57	Z-TOP	1.46	7
15	X-BASE	1.26	7
15	Y-BASE	1.15	7
15	Z-BASE	1.40	7
15	X-TOP	1.40	7
15	Y-TOP	1.01	7
15	Z-TOP	1.59	7
51	X-BASE	1.29	7
51	Y-BASE	2.24	7
51	Z-BASE	1.40	7
51	X-TOP	1.47	7
51	Y-TOP	0.95	7
51	Z-TOP	1.59	7
35	X-BASE	1.21	7
35	Y-BASE	1.71	7
35	Z-BASE	1.22	7
35	X-TOP	1.22	7
35	Y-TOP	0.82	7
35	Z-TOP	1.22	7
15,23,10	X-BASE	1.13	7
15,23,10	Y-BASE	-	Signal Distorted
15,23,10	Z-BASE	1.13	7
15,23,10	X-TOP	1.53	7
15,23,10	Y-TOP	0.89	7
15,23,10	Z-TOP	1.31	7

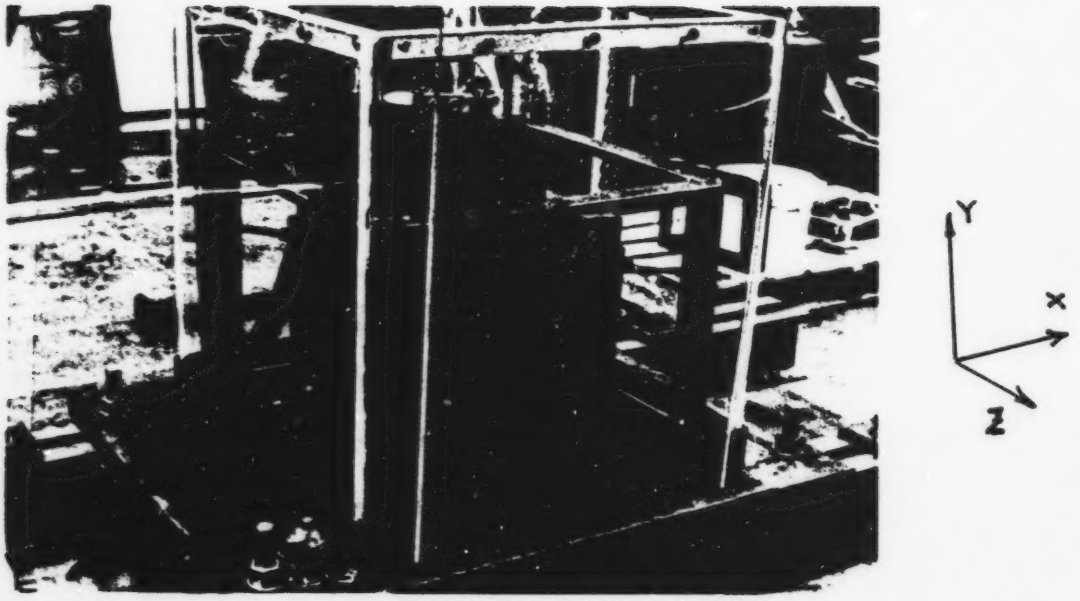


Figure 1

Typical mounting of an Exide FHC-19 cell in single-cell frame. Cell is clamped at four corners with threaded rods. Accelerometers are mounted on the base and on one of the terminal posts.

Axes of vibration are indicated.

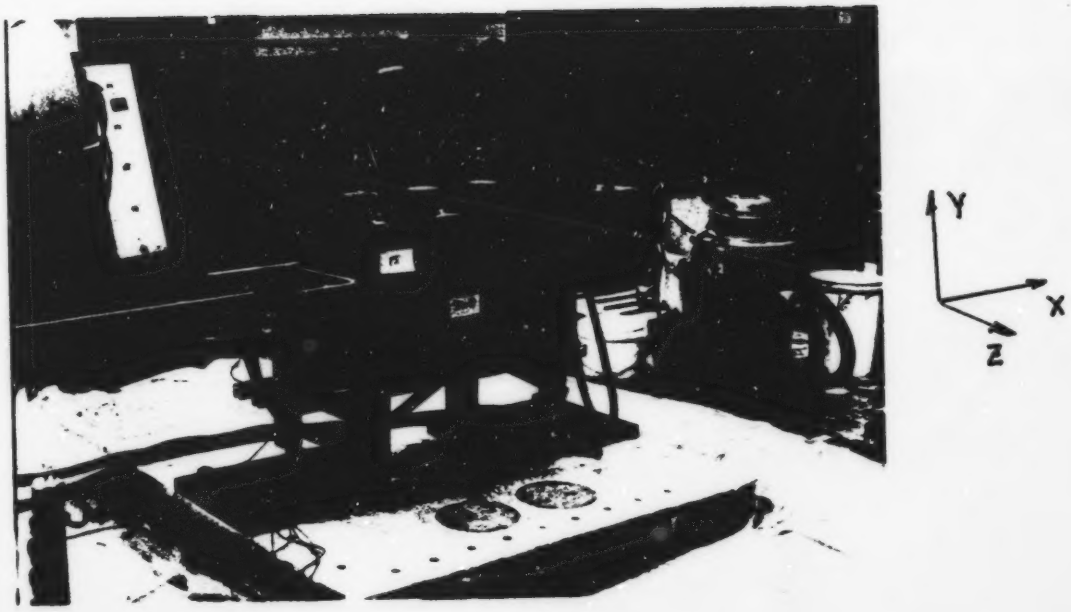
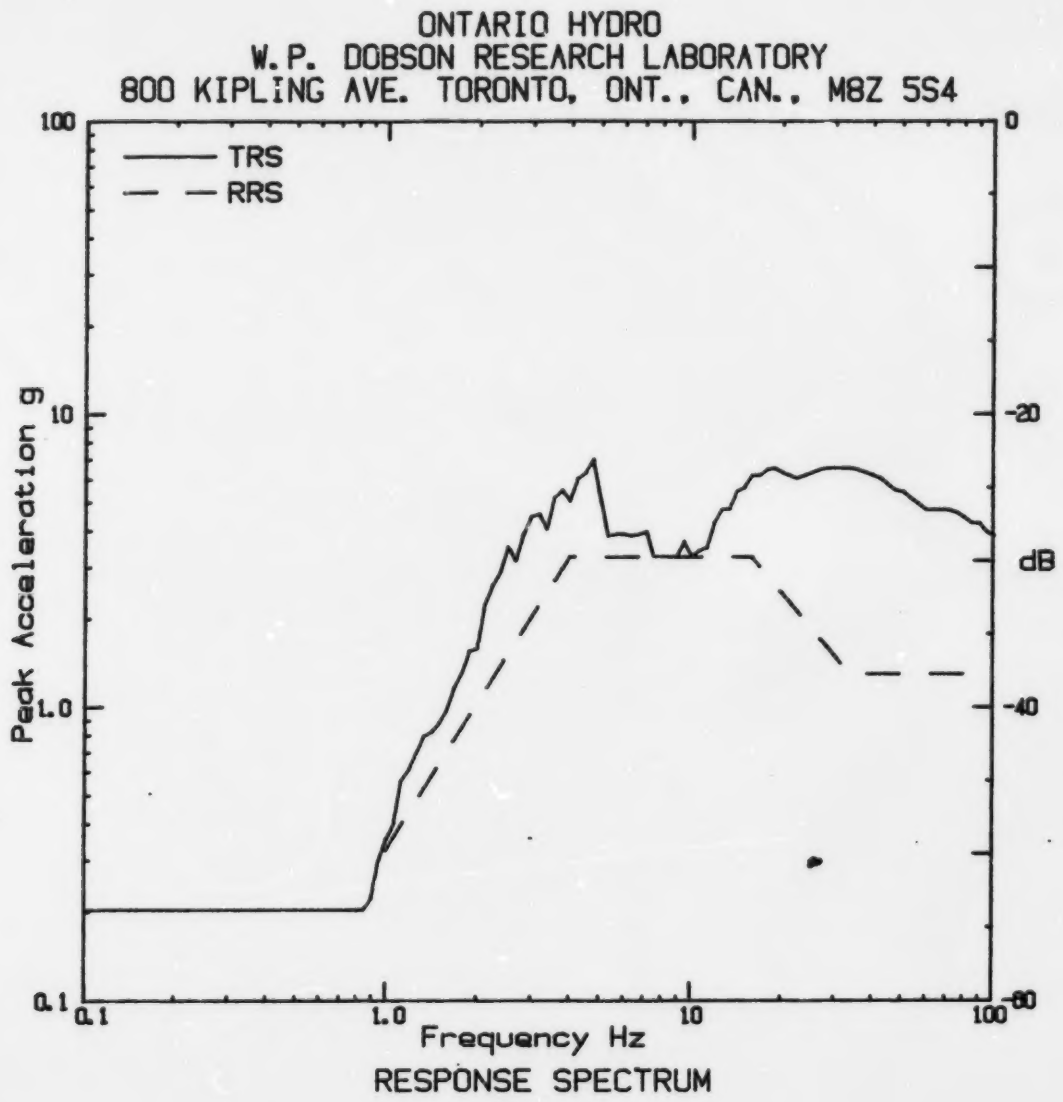


Figure 2

Mounting of Exide FHC-19 cells in multi-cell rack.

Axes of vibration are indicated.



RESPONSE SPECTRUM

FIGURE 3

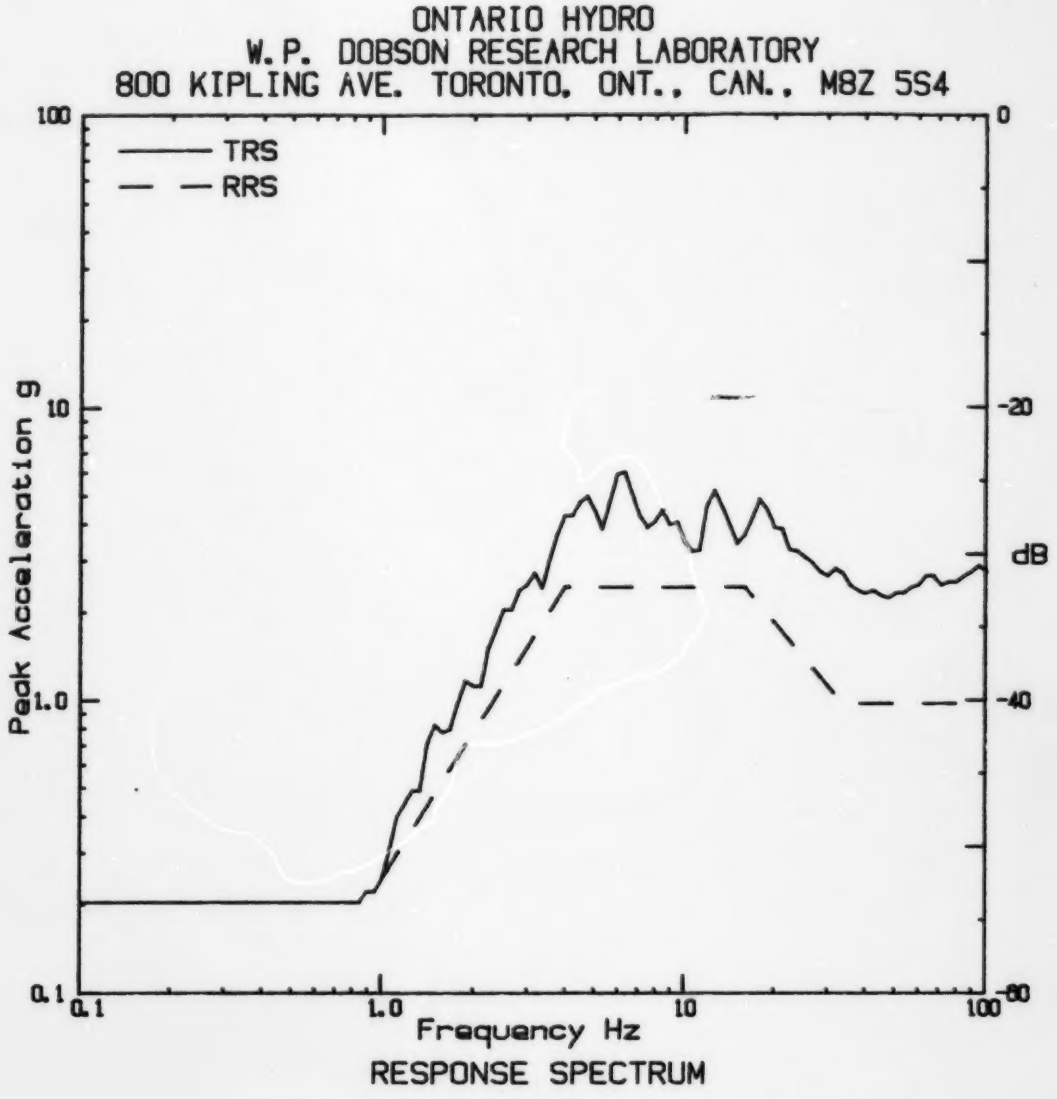
TEST ITEM
Station cell, Exide, Model FHC-19, Serial 57, Calvert Cliffs N.P.P.

PARTICULARS
July 23/84, Time 2:13, Temp('C) 23, Humidity(%) 53, Press (kPa) 100.2,
Graph 5200

SPECIFICATIONS
Specs IEEE 501, Conditions operating, 3 hour rate ; span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.31g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB49, Location base-mounting plate,
Channel 1



RESPONSE SPECTRUM

FIGURE 4

TEST ITEM
Station cell, Exide, Model FHC-19, Serial 57, Calvert Cliffs N.P.P.

PARTICULARS
July 23/84, Time 2:13, Temp('C) 23, Humidity(%) 53, Press (kPa)100.2,
Graph 5201

SPECIFICATIONS
Spece IEEE 501, Conditions operating, 3 hour rate ; span 7

ANALYSIS
Type Maximax, Damping (%)5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=.98g

ACCELEROMETER
Wilcoxon, Serial S761, Range dB49, Location base-mounting plate,
Channel 2

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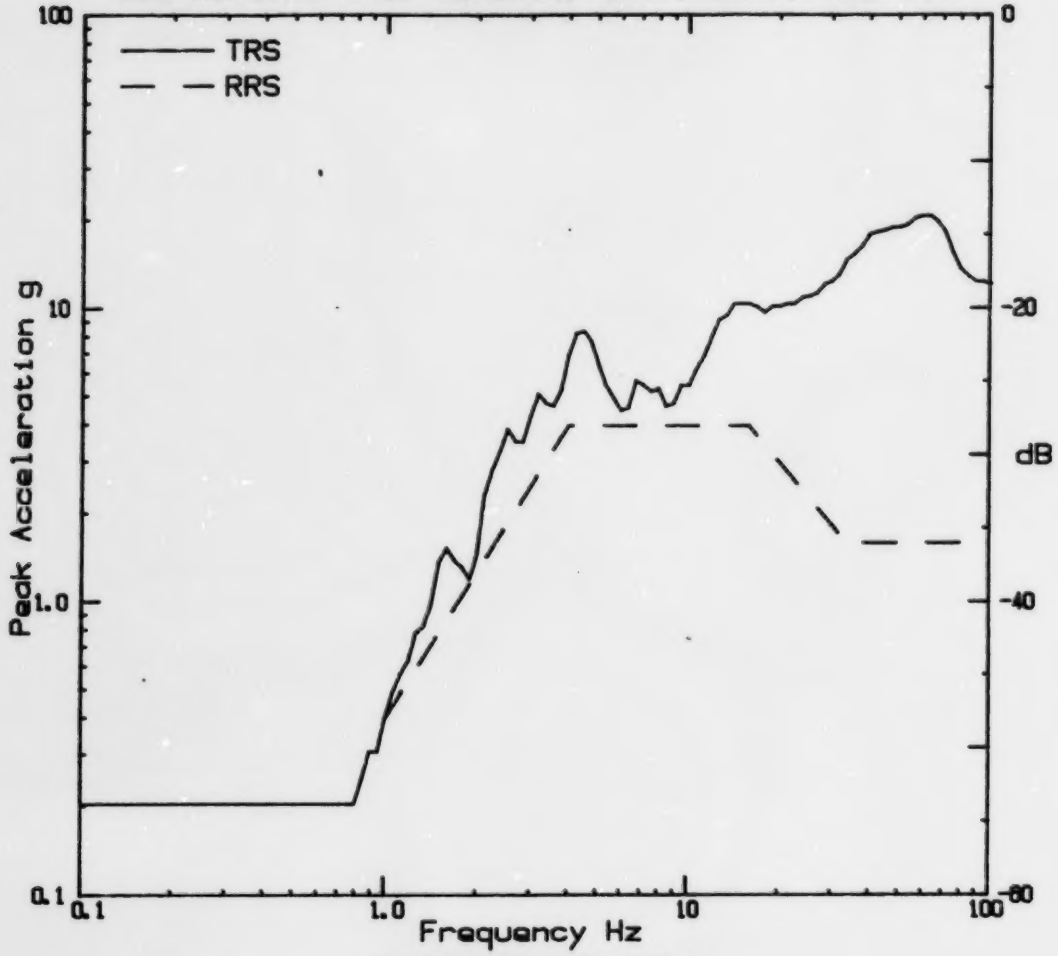


RESPONSE SPECTRUM

FIGURE 5

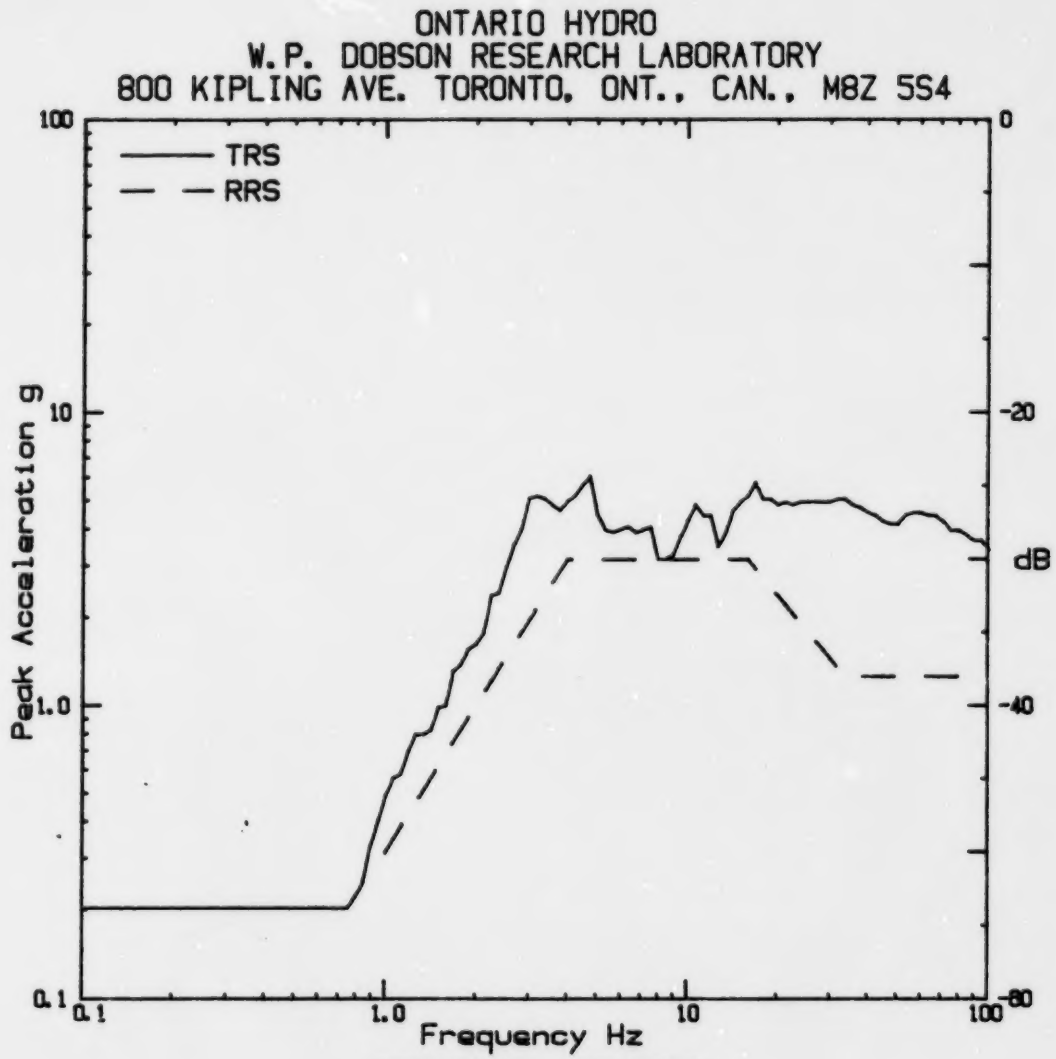
TEST ITEM
Station cell, Exide, Model FHC-19, Serial 57, Calvert Cliffs N.P.P.

PARTICULARS
July 23/84, Time 2:13, Temp('C) 23, Humidity(%) 53, Press (kPa) 100.2,
Graph 5202

SPECIFICATIONS
Spece IEEE 501, Conditions operating, 3 hour rate ; span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.59g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB49, Location base-mounting plate,
Channel 3



RESPONSE SPECTRUM

FIGURE 6

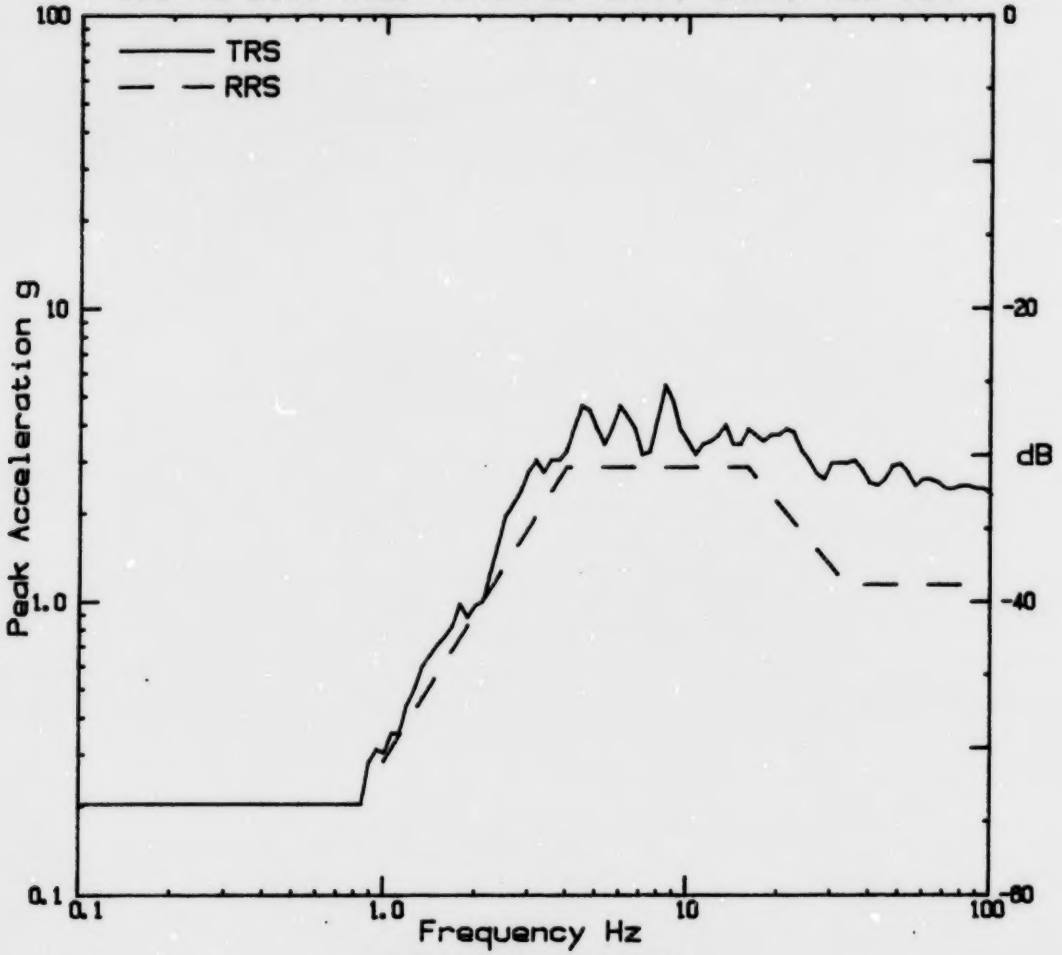
TEST ITEM
Station cell, Exide, Model FHC-19, Serial 15, Calvert Cliffs N.P.P.

PARTICULARS
July 23/84, Time 2:45, Temp('C) 23, Humidity(%) 53, Press (kPa) 100.2, Graph 5206

SPECIFICATIONS
Spece IEEE 501, Conditions operating ; 3 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.26g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB49, Location base-mounting plate, Channel 1



RESPONSE SPECTRUM

FIGURE 7

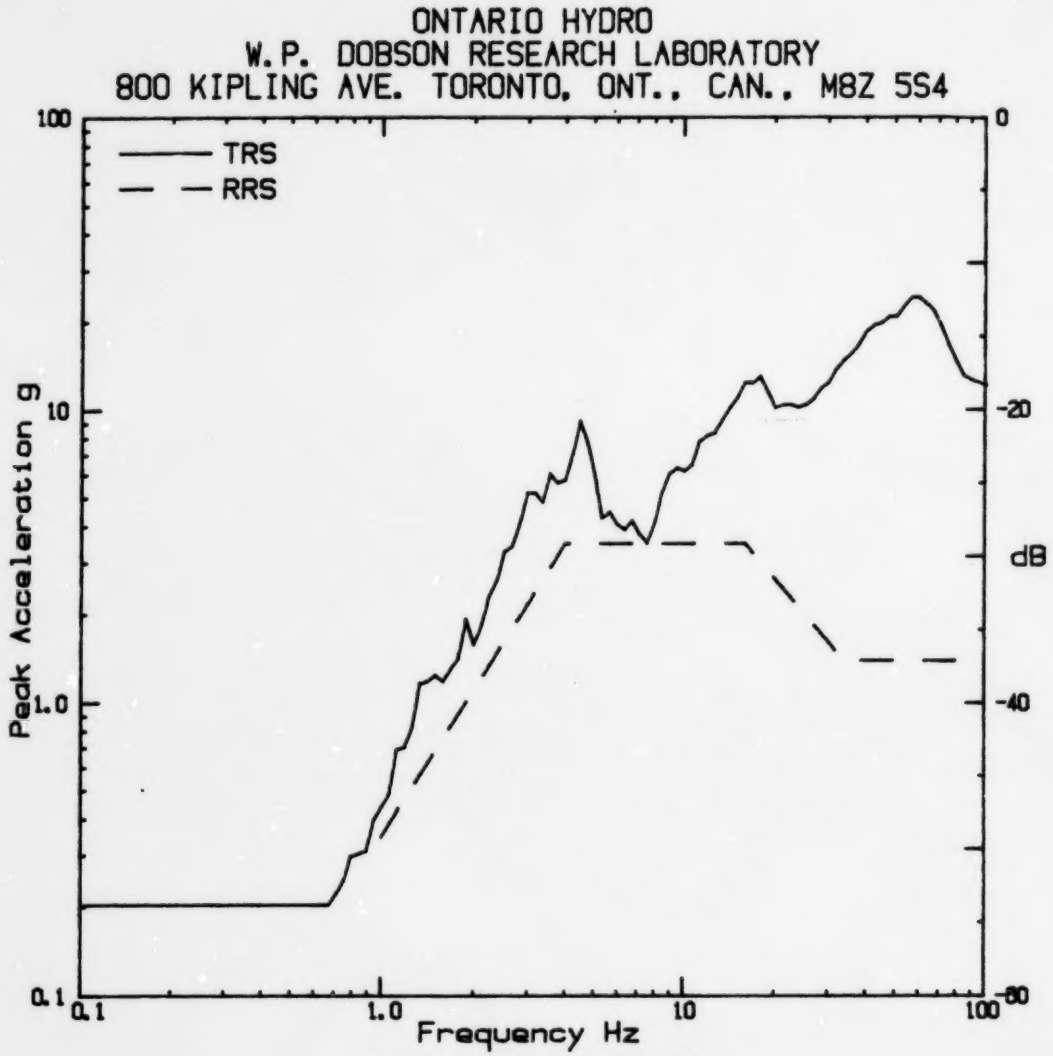
TEST ITEM
Station cell, Exide, Model FHC-19, Serial 15, Calvert Cliffs N.P.P.

PARTICULARS
July 23/84, Time 2:45, Temp('C) 23, Humidity(%) 53, Press (kPa) 100.2,
Graph 5207

SPECIFICATIONS
Spec: IEEE 501, Conditions operating ; 3 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=1.15g

ACCELEROMETER
Wilcoxon, Serial S761, Range dB49, Location base-mounting plate,
Channel 2



RESPONSE SPECTRUM

FIGURE 8

TEST ITEM
Station cell, Exide, Model FHC-19, Serial 15, Calvert Cliffs N.P.P.

PARTICULARS
July 23/84, Time 2:45, Temp('C) 23, Humidity(%) 53, Press (kPa) 100.2, Graph 5208

SPECIFICATIONS
Spec: IEEE 501, Conditions operating ; 3 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z, Shaker tri-axial, ZPA=1.4g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB49, Location base-mounting plate, Channel 3

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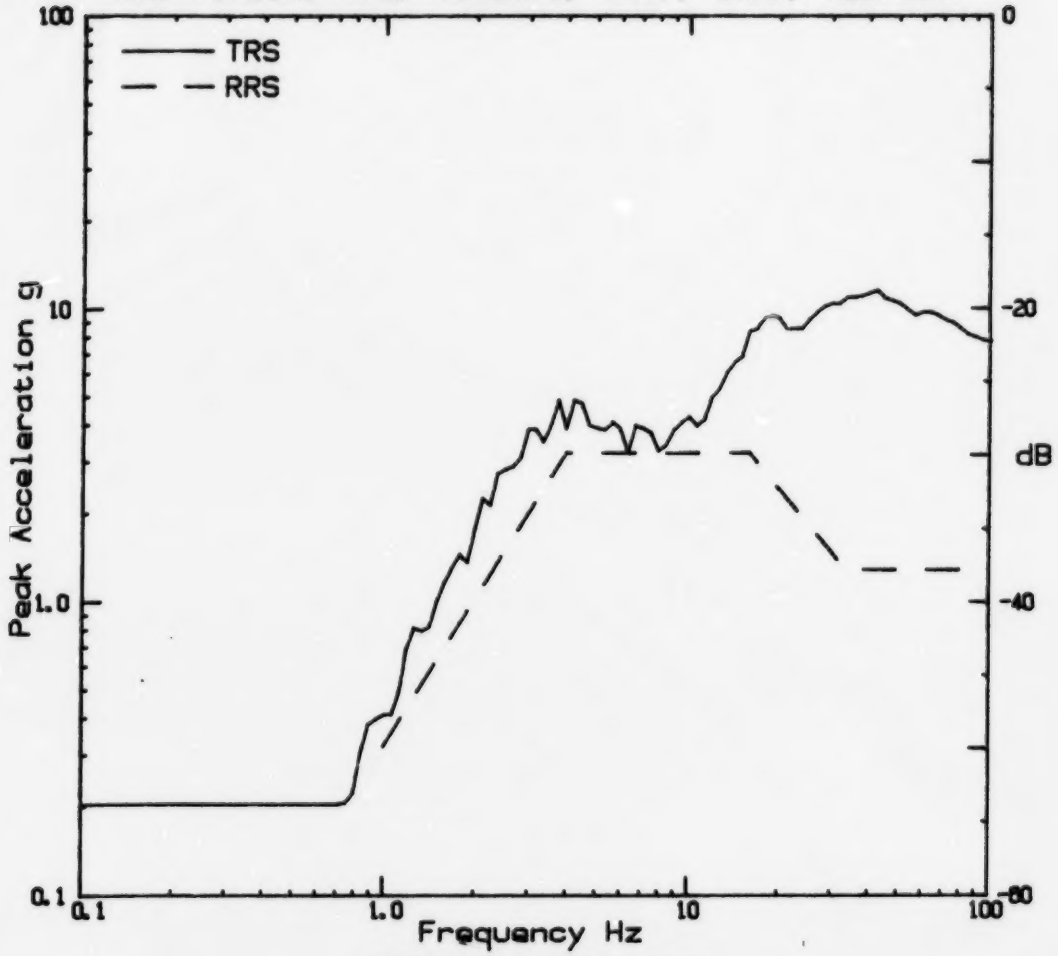


RESPONSE SPECTRUM

FIGURE 9

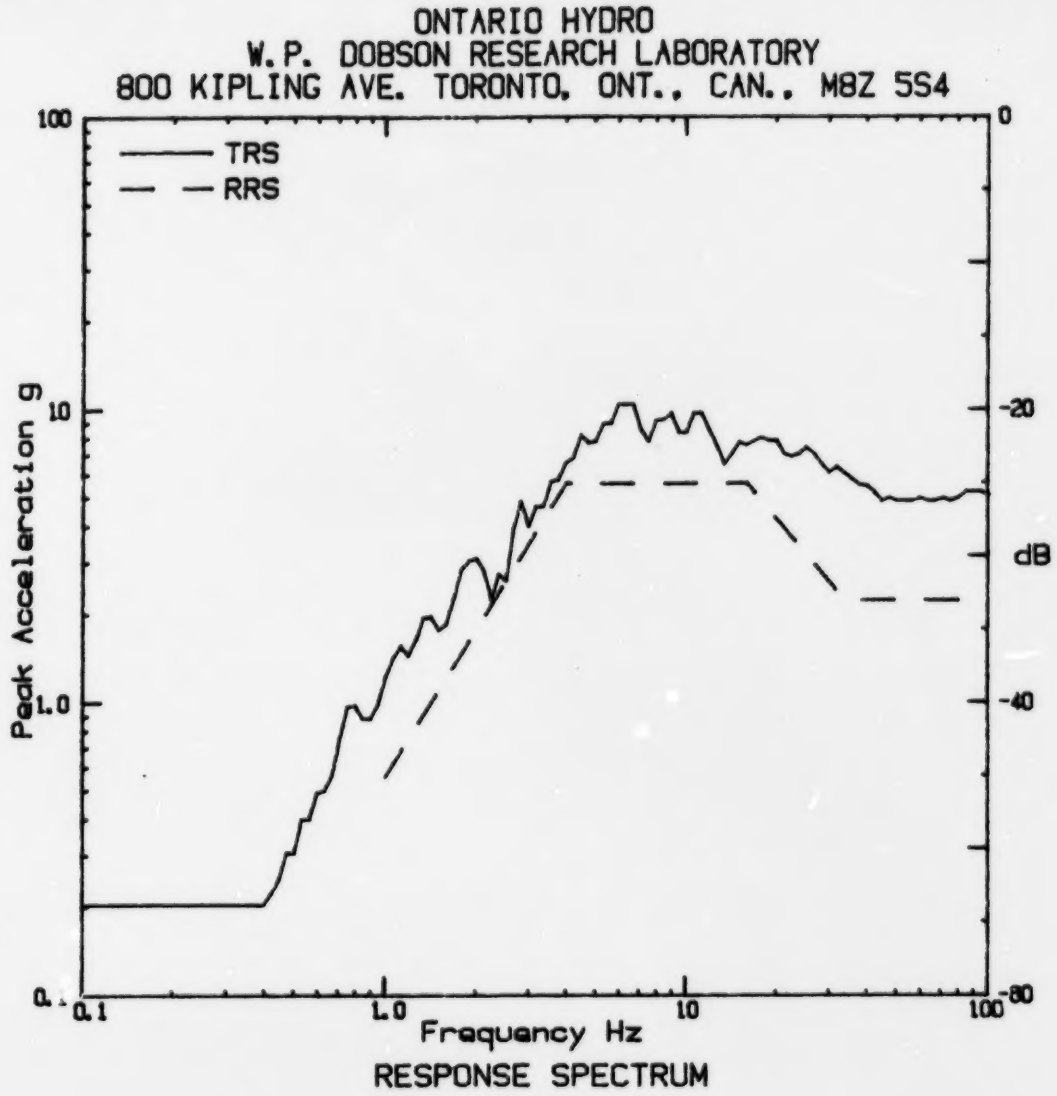
TEST ITEM
Station cell, Exide, Model FHC-19, Serial 51, Calvert Cliffs N.P.P.

PARTICULARS
July 23/84, Time 10:12, Temp('C) 23, Humidity(%) 53,
Press (kPa) 100.2, Graph 5212

SPECIFICATIONS
Spec IEEE 501, Conditions operating ; 3 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.29g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB49, Location base-mounting plate,
Channel 1



RESPONSE SPECTRUM

FIGURE 10

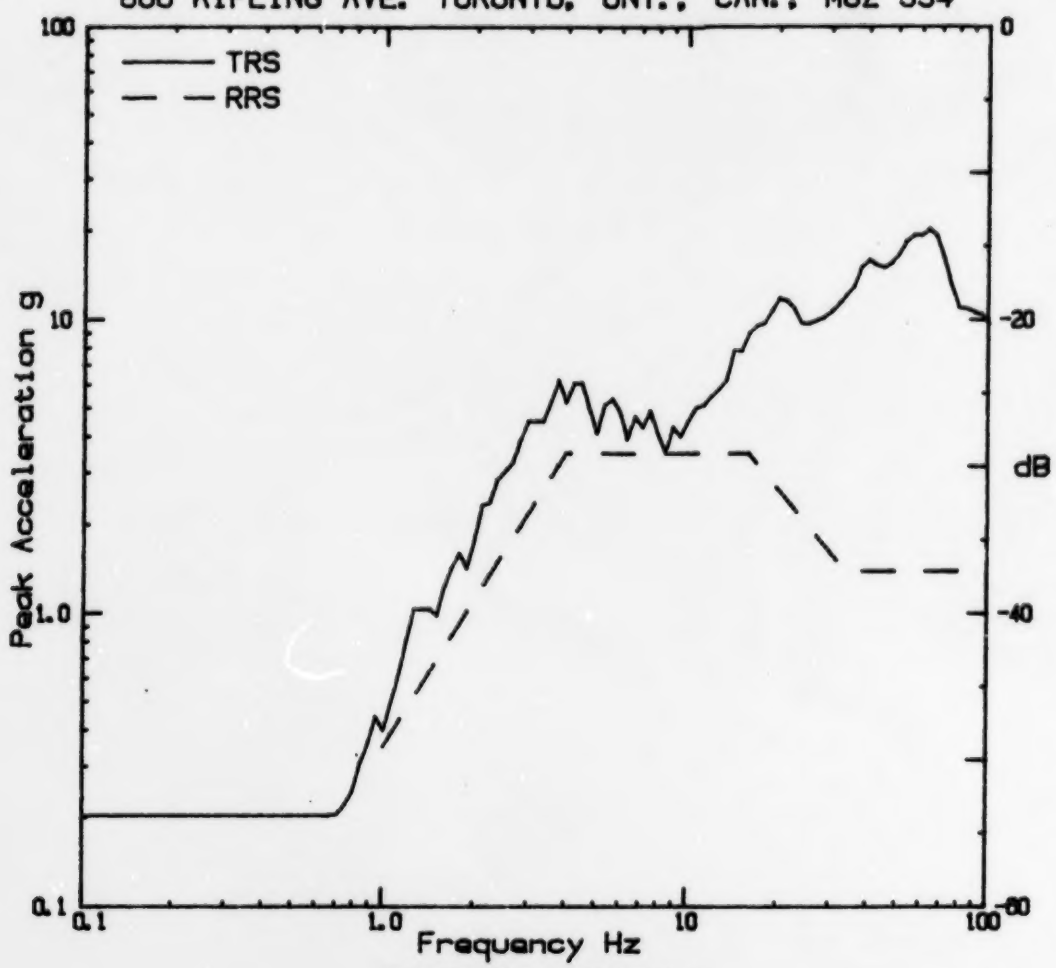
TEST ITEM
Station cell, Exide, Model FHC-19, Serial 51, Calvert Cliffs N.P.P.

PARTICULARS
July 23/84, Time 10:12, Temp('C) 23, Humidity(%) 53,
Press (kPa) 100.2, Graph 5213

SPECIFICATIONS
Spec IEEE 501, Conditions operating ; 3 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Y,
Shaker tri-axial, ZPA=2.24g

ACCELEROMETER
Wilcoxon, Serial S781, Range dB49, Location base-mounting plate,
Channel 2



RESPONSE SPECTRUM

FIGURE 11

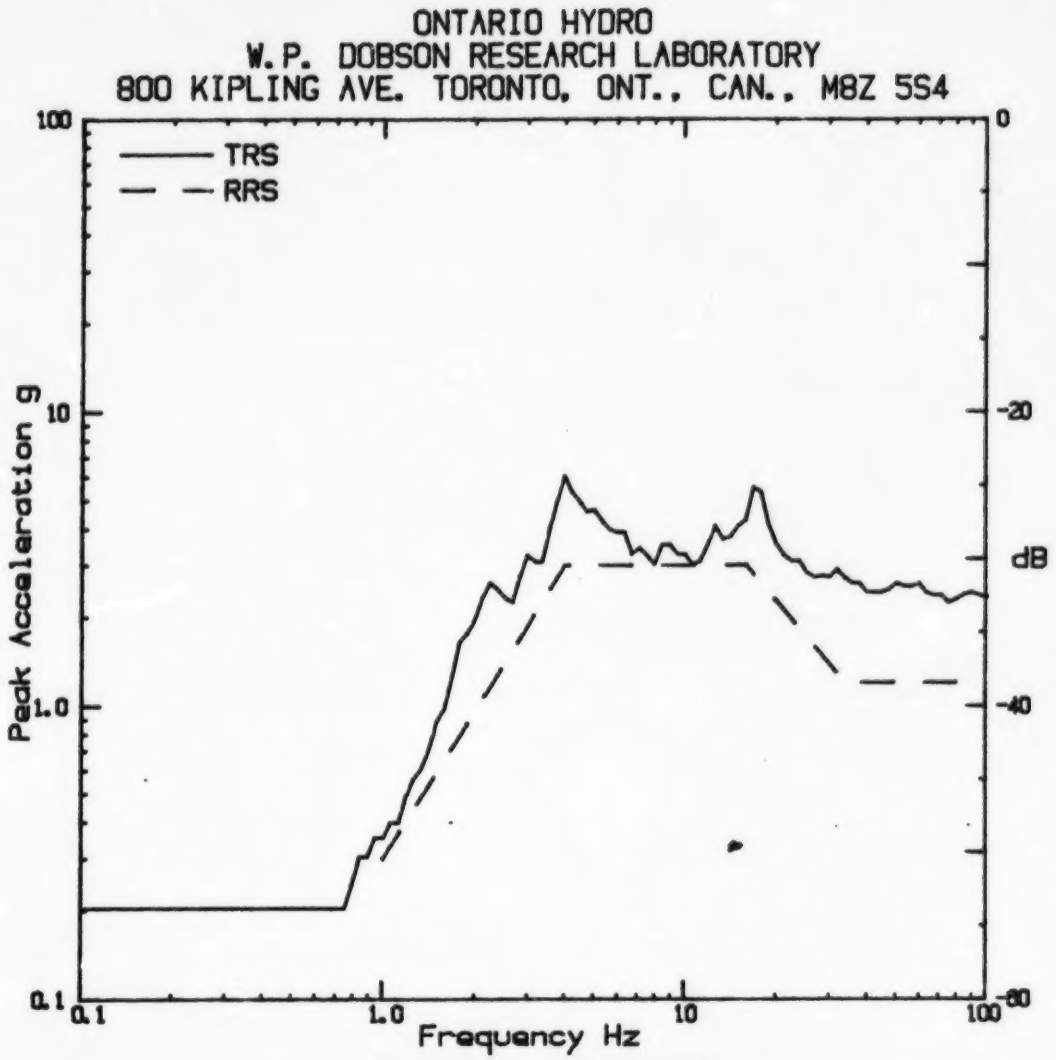
TEST ITEM
Station cell, Exide, Model FHC-19, Serial 51, Calvert Cliffs N.P.P.

PARTICULARS
July 23/84, Time 10:12, Temp('C) 23, Humidity(%) 53,
Press (kPa) 100.2, Graph 5214

SPECIFICATIONS
Spec IEEE 501, Conditions operating ; 3 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.4g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB49, Location base-mounting plate,
Channel 3



RESPONSE SPECTRUM

FIGURE 12

TEST ITEM
Station cell, Exide, Model FHC-19, Serial 35, Calvert Cliffs N.P.P.

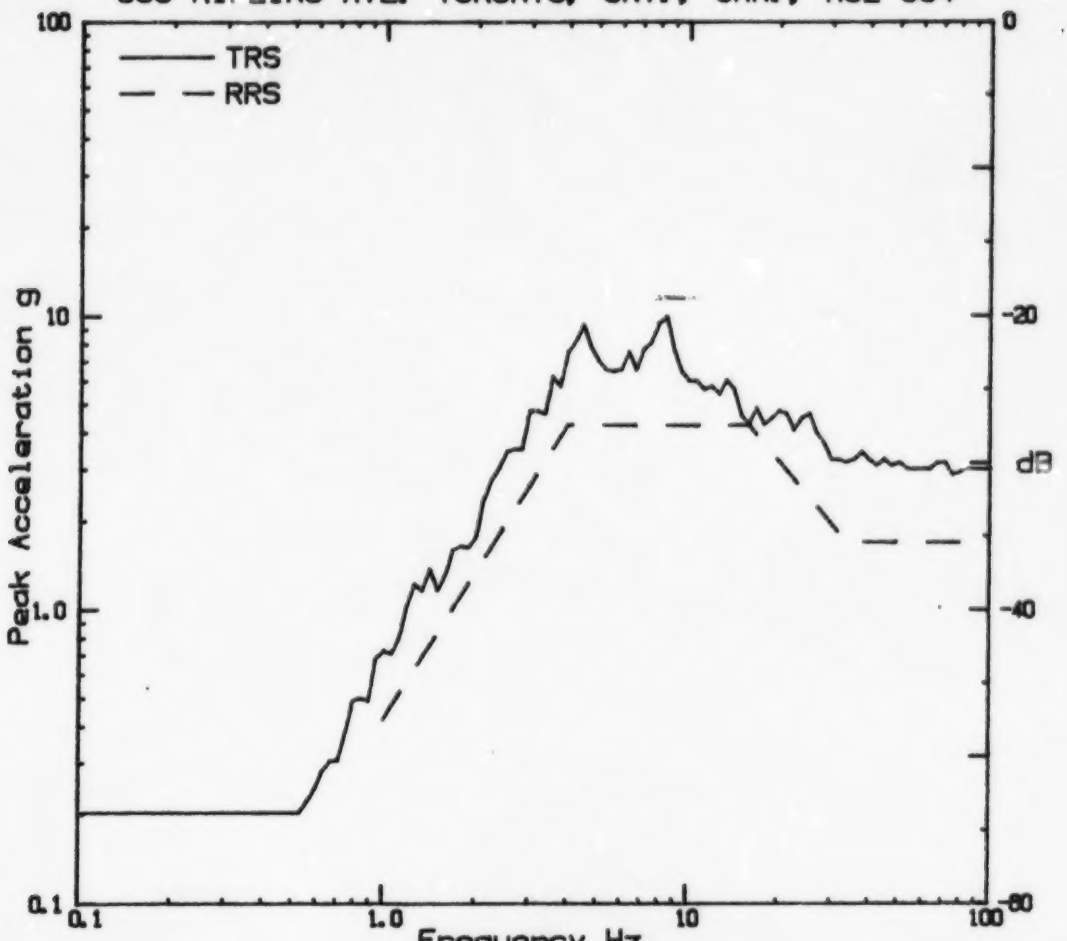
PARTICULARS
July 23/84, Time 11:14, Temp('C) 23, Humidity(%) 53,
Press (kPa) 100.2, Graph 5218

SPECIFICATIONS
Spec IEEE 501, Conditions operating : 3 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.21g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB49, Location base-mounting plate,
Channel 1

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 13

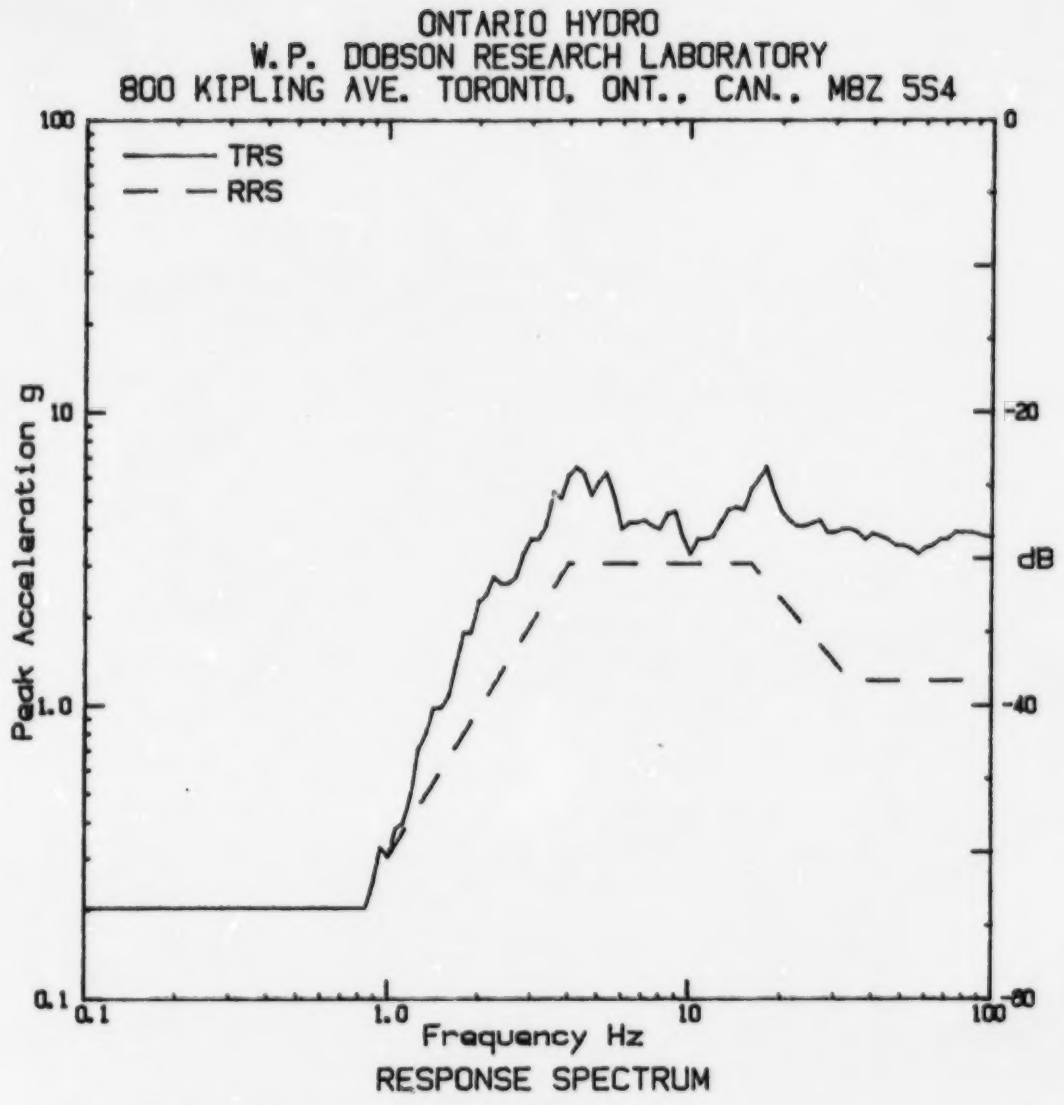
TEST ITEM
Station cell. Exide. Model FHC-19. Serial 35. Calvert Cliffs N.P.P.

PARTICULARS
July 23/84. Time 11:14. Temp('C) 23. Humidity(%) 53.
Press (kPa) 100.2. Graph 5219

SPECIFICATIONS
Spec IEEE 501. Conditions operating ; 3 hour rate. span 7

ANALYSIS
Type Maximax. Damping (%) 5. B.W. = 1/12 Octaves. Axis Y.
Shaker tri-axial. ZPA=1.71g

ACCELEROMETER
Wilcoxon. Serial S781. Range dB49. Location base-mounting plate.
Channel 2



RESPONSE SPECTRUM

FIGURE 14

TEST ITEM
station cell, Exide, Model FHC-19, Serial 35, Calvert Cliffs N.P.P.

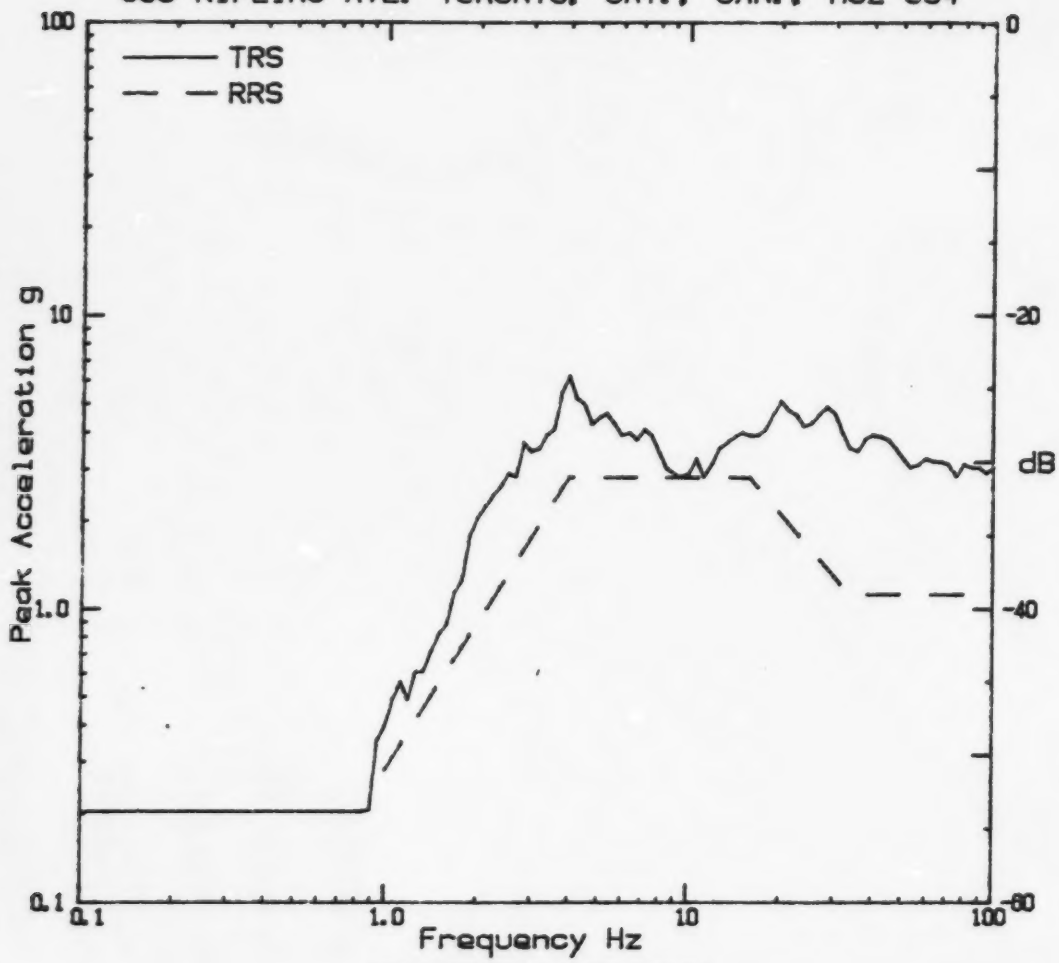
PARTICULARS
July 23/84, Time 11:14, Temp('C) 23, Humidity(%) 53,
Press (kPa) 100.2, Graph 5220

SPECIFICATIONS
Spec IEEE 501, Conditions operating ; 3 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.22g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB49, Location base-mounting plate,
Channel 3

ONTARIO HYDRO
W.P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 15

TEST ITEM
Station cells & Rack, Exide, Model FHC-19, Serial 15,23,10,
Calvert Cliffs N.P.P.

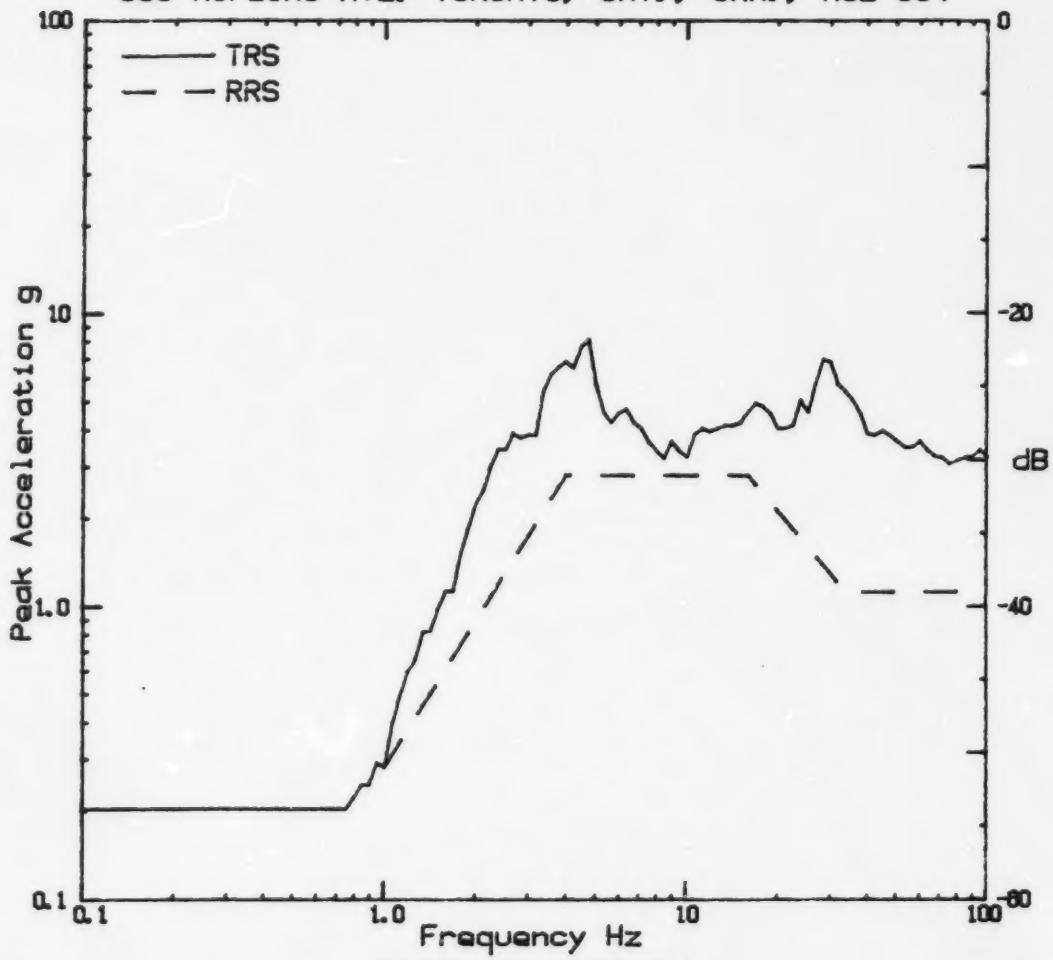
PARTICULARS
July 24/84, Time 2:44, Temp('C) 23, Humidity(%) 55, Press (kPa) 100.3,
Graph 5248

SPECIFICATIONS
Specs IEEE 501, Conditions operating : 1 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis X,
Shaker tri-axial, ZPA=1.13g

ACCELEROMETER
Wilcoxon, Serial S771, Range dB49, Location base-mounting plate,
Channel 1

ONTARIO HYDRO
W. P. DOBSON RESEARCH LABORATORY
800 KIPLING AVE. TORONTO, ONT., CAN., M8Z 5S4



RESPONSE SPECTRUM

FIGURE 16

TEST ITEM
Station calls & Rack, Exide, Model FHC-19, Serial 15.23.10,
Calvert Cliffs N.P.P.

PARTICULARS
July 24/84, Time 2:44, Temp('C) 23, Humidity(%) 55, Press (kPa) 100.3,
Graph 5250

SPECIFICATIONS
Specs IEEE 501, Conditions operating : 1 hour rate, span 7

ANALYSIS
Type Maximax, Damping (%) 5, B.W. = 1/12 Octaves, Axis Z,
Shaker tri-axial, ZPA=1.13g

ACCELEROMETER
Wilcoxon, Serial S297, Range dB48, Location base-mounting plate,
Channel 3